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IFPRI Discussion Paper 00987

May 2010

Dynamic Agricultural Supply Response Under Economic Transformation

A Case Study of Henan Province

Bingxin Yu

Fengwei Liu

Liangzhi You

Development Strategy and Governance Division

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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IFPRI gratefully acknowledges the generous unrestricted funding from Australia, Canada, China, Denmark, Finland, France, Germany, India, Ireland, Italy, Japan, the Netherlands, Norway, the Philippines, South Africa, Sweden, Switzerland, the United Kingdom, the United States, and the World Bank.

AUTHORS

Bingxin Yu, International Food Policy Research Institute
Postdoctoral Fellow, Development Strategy and Governance Division
B.Yu@cgiar.org

Fengwei Liu, Zhengzhou University of Light Industry
Associate Professor, School of Economics and Management

Liangzhi You, International Food Policy Research Institute
Senior Scientist, Enviornment Production and Technology Division
L.You@cgiar.org

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ABSTRACT

China has experienced dramatic economic transformation and is facing the challenge of ensuring steady agricultural growth. This study examines the crop sector by estimating the supply response for major crops in Henan province from 1998 to 2007. We use a Nerlovian adjustment adaptive expectation model. The estimation uses dynamic Generalized Method of Moments (GMM) panel estimation based on pooled data across 108 counties. We estimate acreage and yield response functions and derive the supply response elasticities. This research links supply response to exogenous factors (weather, irrigation, government policy, capital investment, and infrastructure) and endogenous factors (prices). The significant feature of the model specification used in the study is that it addresses the endogeneity problem by capturing different responses to own- and cross-prices. Empirical results illustrate that there is still great potential to increase crop production through improvement of investment priorities and proper government policy. We confirm that farmers respond to price by both reallocating land and more intensively applying non-land inputs to boost yield. Investment in rural infrastructure, human capacity, and technology are highlighted as major drivers for yield increase. Policy incentives such as taxes and subsidies prove to be effective in encouraging grain production.

Key words: dynamic panel model, supply elasticity, acreage and yield response, Generalized Method of Moments (GMM)

JEL Code: D24, C23, Q11

1. INTRODUCTION

The Chinese economy has experienced dramatic transformation in the last few decades. Rapid urbanization and dietary change, coupled with continuous population growth, have resulted in expanding food demand. At the same time, declining agricultural land availability makes grain self-sufficiency, one of the major goals of Chinese agriculture, a considerable challenge. In order to increase output, the government implements comprehensive policies to encourage domestic agricultural supply. For example, the agricultural tax was eliminated countrywide in 2005, reducing production costs for farmers. China has established minimum government procurement prices for such major grain crops as rice and wheat. The minimum procurement price of wheat increased by about 4 percent in 2008 and by 15 percent in 2009 to reflect higher market price and increased production cost. The central government also provides direct subsidies to rice, wheat, and maize farmers based on land area dedicated to grain cultivation. In addition, the central government provides direct fiscal subsidies to major grain-producing counties to ensure high and steady grain production. Since the implementation of the stimulus package in early 2009, the Chinese central government has allocated 21 percent of additional investment, or US$18.7 billion, to rural infrastructure and public services (Ministry of Finance of China 2009).

Despite this record, it remains unclear whether these policies are effective in stimulating grain supply. There is a need for more knowledge of the structural parameters to guide economic policy formulation, especially in light of the urgent need to increase production and farmers' income under economic transformation. Information on the agricultural sector's supply response to changes in prices and rural infrastructure may help policymakers to advance the process of poverty reduction and modernization. If agriculture is highly responsive to policies, policy-induced changes in farmers' response could be effective in increasing production, which in turn could assist in ensuring long-term food security in the country. This study aims to understand the effect of economic transformation on the supply responsiveness of the agricultural sector under the new agricultural policies in China, using Henan province as a case study.

This paper provides some empirical analysis of major crop production in China through estimation of supplies responses to changes in price and non-price factors. It contributes to the literature of supply response analysis in several ways. First, it updates the literature of agricultural production by using the latest data and policy variables from one major grain-producing province in China, allowing us to assess the grain sector under the drastic transformation that occurred over the last decade. Second, it evaluates whether China has exhausted its production potential in the grain sector. It addresses this issue by examining the extent to which grain producers respond to price changes after the implementation of new agricultural policies and by comparing the flexibility of supply response under different policy regimes. It thus identifies constraints in crop production in response to potential policy interventions. Third, this study directly addresses the endogeneity problem in supply response analysis, which has been mostly neglected in the past due to limits in either methodology development or computation power. Panel data are used for this empirical study because they have the distinct advantage of providing spatial and temporal variations. A dynamic panel data approach is chosen to tackle the endogeneity problem with a consistent Generalized Method of Moments (GMM) estimator. Finally, the resulting models expand the supply elasticity estimates for comparison across studies, making it easier to assess the validity of earlier results.

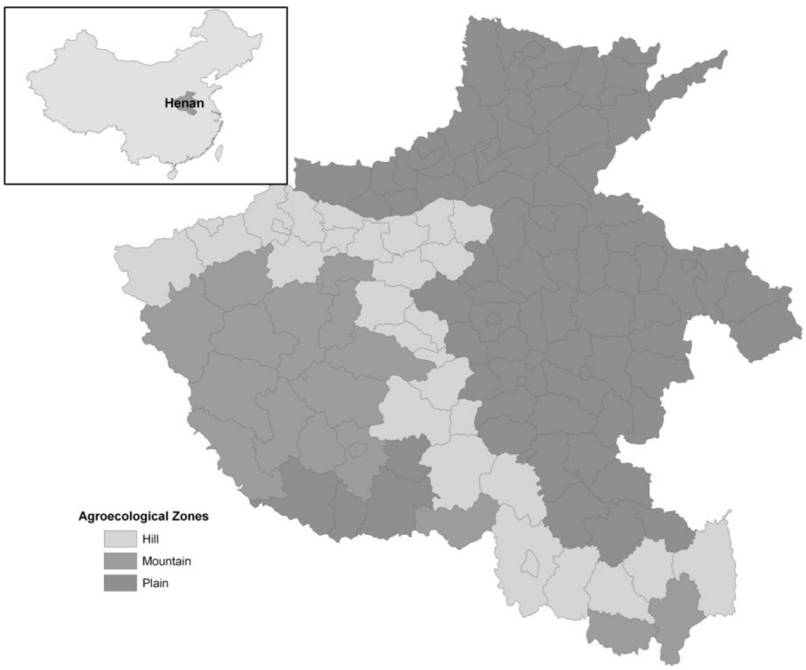
The paper is organized as follows: Following this introduction are reviews of the agricultural sector in Henan province and of past studies. Section three describes the theoretical framework and the dynamic panel GMM method. Section four presents data and definitions of variables, and section five reports empirical results. The final section summarizes conclusions and makes recommendations for policy and future research.

2. BACKGROUND

Agriculture in Henan Province

Henan province is located in central China, southwest of Beijing. The agroecological condition shows three distinct geographic regions: Plain, Hill and Mountain (Figure 1). The Plain zone, lying in the east, is mainly flat, fertile agricultural land. The Mountain zone is to the west, and the Hill zone lies between as a transition. Henan, one of China's 31 provinces, is a major food producer, having produced 11 percent of the country's grain in 2007 (*China statistical yearbook* 2008). The province plays a critical role in the national wheat balance, accounting for more than a quarter of China's total wheat production. It also plays a strategic role in the production of oilcrops, contributing 28.7 percent of national groundnut and 40.1 percent of national sesame output (*China statistical yearbook* 2008). Cotton is another important crop, with 9.8 percent of the national cotton supply coming from Henan province.

Figure 1. Agroecological zones of Henan province



Source: China agroecological zones 1985.

Although currently the agricultural sector contributes only about 14 percent of GDP (gross domestic product) in Henan, it is still of great importance to rural employment and income generation. In 2007, agriculture was still Henan's largest employer, with half the provincial labor force working in agriculture (*Henan statistical yearbook* 2008). In spite of the quick growth in farmers' income from nonfarm activities, traditional agriculture—mainly crop cultivation—is still a major source of income for most farming households. For example, about 45 percent of farmers' total income was derived from crop cultivation in 2006 (*Henan statistical yearbook* 2007). On average a rural Henan household in the lowest income quintile obtains about 64 percent of its income from agriculture. When total household income increases, agriculture's contribution to rural incomes gradually declines but remains substantial. Even among rural households in the richest quintile, more than half of total household income comes from agricultural activities.

Agricultural production has followed a steady upward trend, growing at 6.4 percent from 1978 to 2007 (Table 1). During the three decades, the total area for cultivation remained virtually unchanged, while the use of agricultural inputs has grown tremendously. Chemical fertilizer application and machinery power use per hectare both increased at 8.0 percent per year while pesticide use increased by 6.2 percent. The share of cultivated area under irrigation has grown at 1.7 percent per year, slower than the growth of use of fertilizer, machinery, and pesticide.

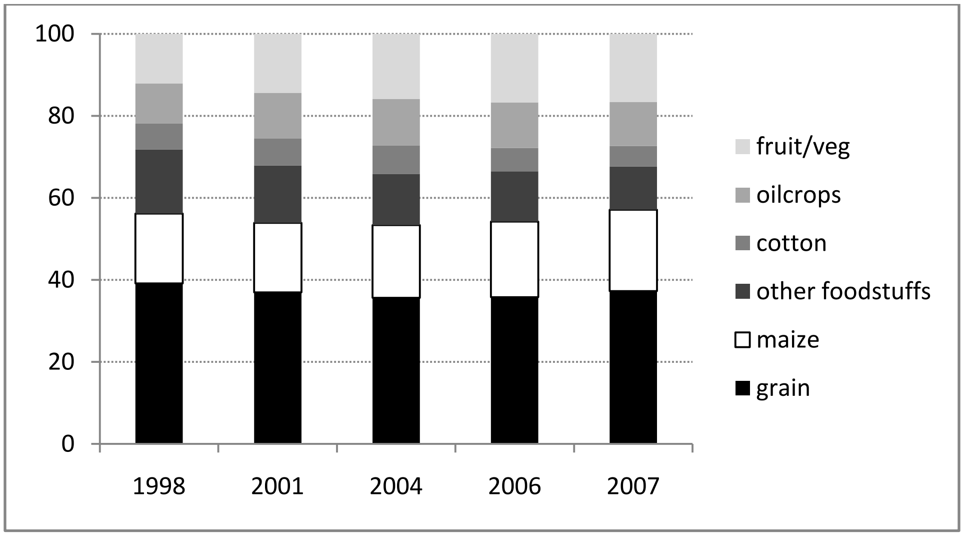
Table 1. Agricultural production in Henan province, 1978–2007

Year	Total output and inputs			Intensity of inputs			
	Output (Bill. Yuan)	Labor (Mill. Persons)	Land (Mill. Hectares)	Share of irrigated land (%)	Machinery (Kw/ha)	Fertilizer (Kg/ha)	Pesticide (Kg/ha)
1978	23.4	2.3	7.2	52.0	1.4	73.4	
1980	31.3	2.4	7.1	49.6	1.7	101.7	
1985	48.8	3.0	7.0	45.4	2.3	204.1	
1990	64.6	3.5	6.9	51.2	3.3	307.5	4.8
1995	82.4	3.9	6.8	59.4	4.6	473.4	11.1
2000	116.2	4.5	6.9	68.7	8.4	611.9	13.9
2004	146.5	4.7	7.2	67.3	10.5	687.1	14.1
2005	161.3	5.0	7.2	67.5	11.0	719.5	14.6
2006	157.7	5.4	7.2	68.3	11.5	750.3	15.5
2007	169.9	5.5	7.2	68.8	12.1	791.0	16.4
			Growth rate (%)+				
1978–1984	12.9	5.9	-0.2	-2.3	7.5	19.2	
1985–1992	4.1	3.2	-0.3	2.9	6.5	10.1	20.3
1993–2000	10.1	2.9	0.0	3.1	12.7	5.8	8.0
2001–2007	6.7	3.7	0.4	0.2	5.8	3.8	2.4
1978–2007	6.4	2.9	0.0	1.7	8.2	8.1	6.2

Source: Henan statistical yearbook 2008.

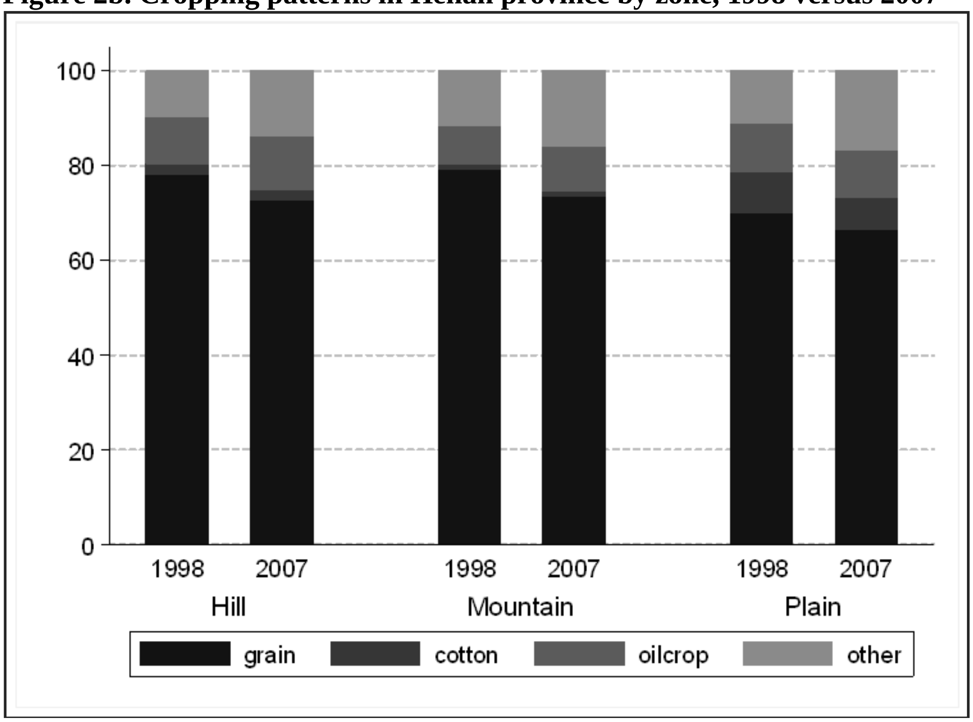
Over the ten years from 1998 to 2007, cropping patterns have mainly shifted away from food grains to non-food grains, mostly from coarse grains, pulses, and tubers (“other foodstuffs”) toward fruits and vegetables (Figure 2a). All three agroecological zones have become more diversified over these years, with cropping patterns having shifted in favor of non-grain crops (Figure 2b). The shares of arable land allocated to oilcrops (mainly groundnut and sesame) and other crops (mainly fruits and vegetables) have increased while the shares of land allocated to grain and cotton have decreased as a result of urban expansion and the shift to more profitable crops. Provincewide, the share of grain-sown area has gradually declined from 72.5 percent in 1998 to 67.0 percent in 2007 (*Henan statistical yearbook* 2008).

Figure 2a. Cropping patterns in Henan province, 1998–2007



Source: Henan statistical yearbook 2008.

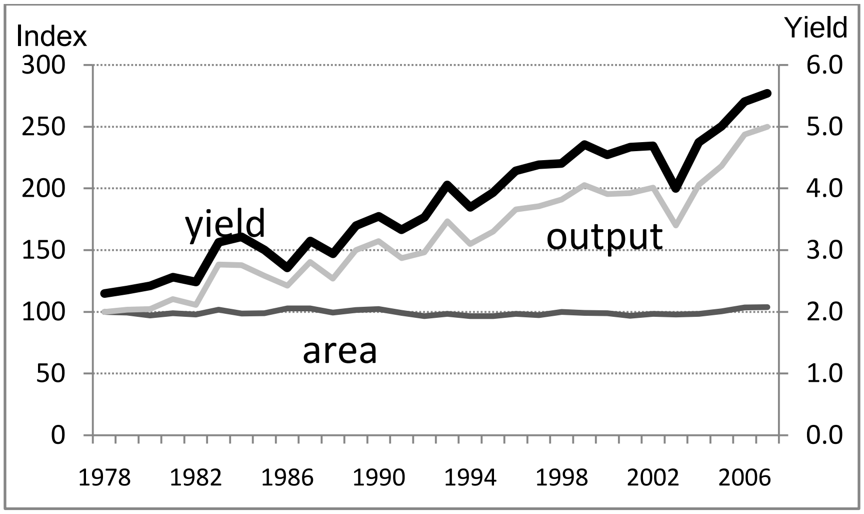
Figure 2b. Cropping patterns in Henan province by zone, 1998 versus 2007



Source: Henan statistical yearbook 2008.

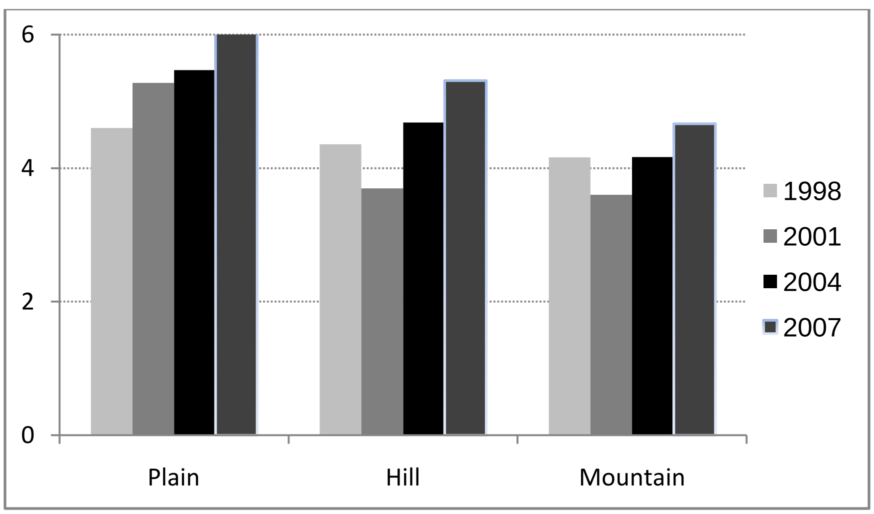
Figure 3 depicts the pattern of grain production over the past three decades. Growth in grain output comes mainly from improved yields since sown area remains unchanged. Average grain yield gained 2.5 percent per year provincewide, although the size of the increase varied by zone (Figure 4). Yield was the highest in the Plain zone due to its beneficial climate and soil conditions, but the increase remained modest at 2.3 percent per year. The Hill zone achieved the highest yield growth at 3.0 percent per year. Both grain yield level and growth rate are the lowest in the Mountain zone, where the increase was 2.2 percent annually. The same yield and growth patterns hold for cotton and oilcrops.

Figure 3. Growth in grain output, area, and yield in Henan province, 1978–2007



Source: Henan statistical yearbook 2008.

Figure 4. Grain yield in tons per hectare in Henan province, 1998–2007



Source: Henan statistical yearbook 2008.

Real prices of outputs and inputs from 1998 to 2007 are reported in Table 2. Market prices of grains dipped slightly around 2000, followed by a quick rebound. During this ten-year period, real prices of wheat and maize increased by 4.1 and 4.8 percent per year, respectively. Prices of cash crops were more volatile. Cotton prices dropped approximately 30 percent from 2000 to 2001 and then more than doubled in 2003. Oilcrops also reported a decade-low price in 2001 and a decade-high price in 2004. The considerable fluctuations of cotton prices certainly have a dampening effect on cotton production. Prices of inputs, except for electricity, increased steadily. Labor costs exhibited the fastest growth at more than 11 percent annually; put another way, by 2007 the average wage had surged to 2.7 times its 1998 level. Other input costs were also on the rise: Fertilizer price grew by 4.0 percent and irrigation cost by 2.0

percent annually. Growth in output prices and input costs outpaced inflation, which was 0.2 percent per year.

Table 2. Real output prices and input costs in Henan province, 1998–2007

	Output price				Input cost				
	Wheat	Maize	Cotton	Oilcrops	Wages	Fertilizer	Irrigation	Electricity	CPI
Year	(Yuan per kg)	(Yuan per kg)	(Yuan per kg)	(Yuan per kg)	(Yuan per year)	(Yuan per kg)	(Yuan per mu)	(Yuan per kwh)	
1998	1.22	1.08	12.51	2.20	4,028	3.23	13.09	0.58	103.3
1999	1.14	0.87	8.00	2.23	4,481	3.23	17.29	0.60	100.1
2000	0.95	0.83	11.52	1.65	4,754	3.00	23.78	0.61	98.6
2001	1.05	0.95	8.16	1.73	5,390	2.86	16.18	0.62	97.9
2002	1.02	0.98	10.79	1.83	6,077	2.82	19.92	0.63	96.6
2003	1.34	1.21	16.58	2.08	6,379	3.01	16.12	0.63	96.5
2004	1.48	1.22	11.51	2.58	6,942	3.53	17.55	0.61	99.2
2005	1.33	1.15	13.02	2.09	7,922	4.02	18.34	0.60	100.0
2006	1.43	1.31	12.91	2.23	9,440	4.06	19.05	0.60	101.0
2007	1.54	1.41	13.92	2.40	10,883	4.37	20.23	0.58	104.8
Annual growth rate (%)	4.10	4.83	3.94	2.01	11.20	4.00	2.04	-0.18	0.20

Note: Prices are expressed as 2005 constant prices. CPI: Consumer Price Index
Source: Henan statistical yearbook 2008.

Past Studies in China

Previous estimates of supply elasticities point to a pattern of low and positive price response in agricultural supplies around the world (Albayrak 1998). This is generally the case for grains in China. China has witnessed rapid growth of grain production since the 1980s, and there is rich literature on the supply of food crops in the country. These studies analyzed responses to changes in the price and quantity of inputs and outputs. They analyzed crop supply response from the perspectives of institutions, price, technology, and investment. By comparing the role of price signals and various inputs in grain production, especially through analyses of own-price elasticities, these studies tried to identify the possible causes of Chinese output growth in the general agricultural sector and in specific crops.

Huang (1991) found that the price elasticities of wheat and other grain crops were above unity (1.05 and 1.51 respectively) and the rice elasticity was as low as 0.20. Huang’s estimates were higher than the results of Carter and Zhong (1988), who estimated that the price elasticity was 0.15 for winter wheat and 0.27 for spring wheat. Chen and Buckwell (1991) demonstrated a high price cross-elasticity between grain and cotton and found the relative price of inputs (fertilizer and pesticide) to outputs was important to grain production. In addition, some research has set supply price elasticity in supply simulations based on previous empirical evidence. The World Bank (1991, annex 4, Table C) designated price elasticity for supply as 0.2 for rice, wheat, and soybeans and 0.3 for corn and tubers.

In the 1990s, some studies measured the impact of grain price change on production under a dual-track price system to explore the deeper reasons for grain output growth. Lin (1992) directly estimated a supply response function and the relative market price (MP) elasticity for gross value of crop output as 0.35 and relative state procurement price (GP) elasticity as 0.24. These figures indicated a stronger response to market price than to procurement price and highlighted the growing importance of the market in the decisionmaking process of agricultural production at the household level. Lu (2002) applied a

Nerlovian model to several grain crops in Zhejiang province and pointed out that the influence of different prices varies considerably across crops. Acreage of early rice, late rice, and winter wheat increased by 0.041, 0.039, and 0.188 percent respectively if market price increased by 1 percent from the previous year. At the same time, the impact of quota prices was not significant. In the case of barley, quota price is the most important factor, with an elasticity of 0.469. The low responsiveness of rice may be due to its dominant role in the region's farming systems. Lu's results also revealed a substitute relationship between early and late rice and a competitive relationship between winter wheat and barley.

Instead of directly estimating output supply responses, USDA (2000) captured the adjustments of output and input use in China's grain sector due to changes in prices. The researchers did this by deriving interrelated output supply and input demand functions from a restricted translog profit function. The four grains in this study were generally price elastic in two sample periods. In 1978–1985, own-price output elasticity was estimated at 1.48 for rice, 0.96 for wheat, 1.03 for maize, and 3.72 for soybeans. In the later period of 1986–1997, the researchers reported smaller elasticities than the previous period for rice, wheat, and soybeans: 1.01, 0.96, 1.17, and 3.25, respectively. The author attributed this to changes in relative agricultural prices when prices of non-grain crops increased. The supply response elasticities to factor prices were negative, but they declined in magnitude as the economy grew. Details of each study are reported in Table 3.

In summary, the short-run own-price elasticity of the grain sector ranges from 0.24 to 0.35, but the magnitudes of elasticities vary substantially across different crops: wheat 0.19–0.96, maize 1.17, soybean 0.32–3.25, and barley 0.20. By convention, an elasticity less than unity is considered inelastic. The short-run response in agriculture tends to be low because the main inputs—land, labor, and capital—are fixed. However, while changes in product prices typically (but not always) explain a relatively small proportion of the total variation in output, short-run changes in output are often influenced by external shocks like weather and pests. In the long run, supply responses are due to such factors as more effective resource allocation and improvement in technology, which bring in higher yields. This issue has also been addressed by a number of researchers; for example, Mundlak (1985) and Binswanger (1990) argued that more resources, better technology, and infrastructure investments such as roads, markets, irrigation, and agricultural extension promote agricultural outputs. The long-run elasticity estimates are greater than the reported results in the short run because the desired factor reallocation becomes more complete as factors that are fixed in the short run become variable. This is confirmed by the study of Huang and Rozelle (1998), which found larger long-run elasticities and smaller short-run elasticities. The level of data aggregation and choice of alternative crops also contribute to the size of elasticity.

Table 3. Elasticity estimates in supply function from previous studies

Authors	Data	Model	Period	Crop	Input price elasticity	Own-price elasticity
Lin (1992)	28 provinces	Supply response function	1970-87	Gross value of crop output		Market price/input price(MP)[1]: 0.35 State procurement price/input price (GP): 0.24
USDA (2000)	Province	Restricted translog profit function	1978-85	Rice output	Labor: -1.51 Intermediates and capital: -1.43	1.48
				Wheat output	Labor: -1.69 Intermediates and capital: -1.45	0.96
				Maize output	Labor: -0.84 Intermediates and capital: -2.55	1.03
				Soybean output	Labor: -0.79 Intermediates and capital: -4.65	3.72
			1986-97	Rice output	Labor: -1.09 Intermediates and capital: -0.67	1.01
				Wheat output	Labor: -1.32 Intermediates and capital: -0.74	0.96
				Maize output	Labor: -0.25 Intermediates and capital: -2.12	1.17
				Soybean output	Labor: -0.37 Intermediates and capital: -3.77	3.25
Lu (2002)	11 regions in Zhejiang Province	Nerlovian supply	1985-97	Winter barley acreage		Quota price: 0.469 Market price: 0.199 Relative price of winter wheat to winter barley: -0.021 Relative price of early rice to winter barley: 0.055
				Winter wheat acreage		Quota price: 0.105 Market price: 0.188 Relative price of winter wheat to winter barley: -0.021 Relative price of early rice to winter wheat: 0.021
Huang and Rozelle (1998)	province	Cost Function	1975-92	Other grain output	Fertilizer price short-run: -0.134 Fertilizer price long-run: -0.136	Short-run: -0.072 Long-run: -0.041 Rice price short-run: 0.366 Rice price long-run: 0.373 Cash grain price short-run: 0.039 Cash grain price long-run: 0.041
Wang (2000)	China	Nerlovian supply	1952-97	Soybean area		Short-run: 0.324 Long-run: 0.486

Note: The price elasticity of MP and GP are calculated using coefficients and sample mean provided in the paper by the authors.
Source: USDA 2000.

3. THEORETICAL AND ANALYTICAL DEVELOPMENTS

Since grain, cotton, and oilcrops are part of a farming system in which crops compete for resources, the estimation of the supply response for one crop should take competing crops into consideration. The econometric approach of the present study involves a Nerlovian model, updated with dynamic analysis of supply response.

Theoretical Model

Broadly speaking, two frameworks have been developed in the literature for conducting supply response analysis. The first approach is a Nerlovian expectation model, which facilitates the analysis of both the speed and the level of adjustment of actual acreage and yield toward desired acreage. The second is the supply function approach, derived from the profit-maximizing framework. Just (1993) and Sadoulet and de Janvry (1995) produced excellent reviews of these approaches and of empirical studies employing them. The supply function approach requires detailed input prices. Moreover, the Chinese agricultural input markets are not functioning in a competitive environment, particularly the land and labor markets. Since our interest is in just the output supply function, this study uses a Nerlovian approach.

Usually, the observed prices are market or farm gate prices after production has occurred, while production decisions have to be based on the prices farmers expect to receive several months later, at harvest time. Nerlovian models are built to examine the farmers' output reaction based on price expectations and partial area adjustment (Nerlove 1958). The nature of Nerlovian models is ad hoc specifications of supply response including partial adjustment and expectation formation. Time series data are often used for the commodity under study to capture the dynamics of agriculture production. The Nerlovian supply response approach enables us to determine short- and long-run elasticities. It also has the flexibility to introduce nonprice production shift variables into the model.

Models of the supply response of crops can be formulated in terms of yield, area, or output response. For instance, the desired area to be planted in a crop in period *t* is a function of expected relative prices *P* and a number of exogenous shifters *Z*.

$$\mathrm{A}_t^d = \alpha_1 + \alpha_2 \mathrm{P}_t^e + \alpha_3 \mathrm{Z}_t + \mathrm{u}_t, \tag{1}$$

where A_t^d is the desired cultivated area in period *t*; P_t^e is the expected prices of the crop and of other competing crops, and expected input costs; Z_t is a set of other exogenous shifters, including fixed private and public factors, weather, etc.; u_t accounts for unobserved random factors affecting the area under cultivation, $\mathrm{E}(\mathrm{u}_t) = 0$, $\mathrm{E}(\mathrm{u}_t) = 0$; and α_i is the parameter to be estimated. Specifically, α_2 is the long-run coefficient of supply response.

Because full adjustment to the desired allocation of land may not be possible in the short run, the actual adjustment in area will be only a fraction δ of the desired adjustment.

$$\mathrm{A}_t - \mathrm{A}_{t-1} = \delta(\mathrm{A}_t^d - \mathrm{A}_{t-1}) + \mathrm{v}_t. \tag{2}$$

where A_t is the actual area planted in the crop; δ is the partial-adjustment coefficient; and v_t is a random term, $\mathrm{E}(\mathrm{v}_t) = 0$.

The price that the producer expects to prevail at harvest time cannot be observed. Therefore, one has to specify a model that explains how the agent forms expectations based on actual and past prices and other observable variables. For example, farmers adjust their expectations as a fraction γ of the deviation between their expected price and the actual price in the last period, *t–1*.

$$\mathrm{P}_t^e - \mathrm{P}_{t-1}^e = \gamma(\mathrm{P}_{t-1} - \mathrm{P}_{t-1}^e) + \mathrm{w}_t, \text{ or}$$
$$\mathrm{P}_t^e = \gamma \mathrm{P}_{t-1} + (1-\gamma)\mathrm{P}_{t-1}^e + \mathrm{w}_t,\ 0 \le \gamma \le 1.$$
$$0 \le \gamma \le 1, \tag{3}$$

where P_t^e is the expected price for period *t*; P_{t-1} is the price that prevails when decisionmaking for production in period *t* occurs; γ is the adaptive-expectations coefficient; and w_t is a random term, $E(w_t) = 0$.

Since A_t^d and P_t^e are unobservable, we eliminated them from the system. Substitution of Equation (1) and (3) into Equation (2) and rearrangement gives the reduced form

$$A_t = \pi_1 + \pi_2 P_{t-1} + \pi_3 A_{t-1} + \pi_4 A_{t-2} + \pi_5 Z_t + e_t, \tag{4}$$

where

$\pi_1 = \alpha_1 \delta \gamma$;

$\pi_2 = \alpha_2 \delta \gamma$, the short-run coefficient of supply response;

$\pi_3 = (1 - \delta) + (1 - \gamma)$;

$\pi_4 = -(1 - \delta)(1 - \gamma)$;

$\pi_5 = \alpha_3 \delta$; and

$e_t = v_t - (1 - \gamma)v_{t-1} + \delta u_t - \delta(1 - \gamma)u_{t-1} + \alpha_2 \delta w_t$.

Equation (4) is the estimable form of the supply response model defined by Equations (1), (2), and (3), since only the actual output rather than the optimal output is observed in reality. The reduced form is a distributed lag model with lagged dependent variable. The short-run price response of each explanatory variable is estimated directly by its coefficient, and the long-run price response is obtained by dividing short-run elasticities by an adjustment coefficient (the coefficient of the lagged dependent variables).

As expected, the long-run supply response is greater than the short-run supply response, because both δ and γ are smaller than one. If the adjustment coefficient is close to one, it implies that farmers' adjustment of actual acreage to desired acreage is fast. On the other hand, if the adjustment coefficient is close to zero, the adjustment takes place slowly.

If yield or output instead of area is chosen as dependent variable in the response function, we can obtain the short- and long-run yield or supply response with respect to own price following the same logic by tailoring the model specification to the new research question. For the yield response function, for example, the variables included in the reduced form would be previous yield, price, infrastructure variables, and a time trend.

Specification Issues

There are many arguments to support the notion that farmers in developing countries are not sensitive to economic incentives such as price. The numerous crop-level studies available for developing countries have, for the most part, arrived at the same finding: that the supply response is less elastic than in developed countries. Reasons these studies cite for the poor response range from constraints on irrigation and infrastructure to the lack of complementary agricultural policies and subsidies. There are varying results on the degree of response. Two sets of explanations are offered as to why the results vary and what the analysis overlooks. The first set of reasons focuses on conceptual problems in identifying correct prices and exogenous variables. The second set of reasons points to the formulation of empirical models—for instance, the specification of supply function, use of distributed lag, failure to recognize model identification problems, and improper choice of nonmarket factors (Albayrak 1998). In short, the farmers are responding to incentives, but their response might be limited and subject to various constraints.

Farmers' production behavior responds to both price and nonprice factors. Price factors include expected output prices and input costs. The nonprice factors influencing supply response include exogenous technology shifters (to improve yield) and factors of physical production, such as rainfall, irrigation, market access for both inputs and output, investment, and education. Since model specification influences the values and the significance of the estimated supply elasticities, considerable judgment is required to select the variables that matter. Assuming there are several competing crops, several inputs, several technologies, and several environmental variables, the hypothesized supply function is expressed as follows:

Supply = *f* (expected output, own-price and expected price of alternative crops, input price, technology, physical environment, policy environment).

Statistical estimation requires decisions about the proper specification of variables apart from estimation-related problems. Many scholars use relative profitability rather than relative price, claiming it better explains farmers' choices. However, profit calculation has its own measurement problems, such as identifying proper imputation methods for farmers' own inputs and common costs to compute profits. Moreover, price is a direct policy instrument, so the results are handy for policy purposes. Therefore, in this paper we use output price as the incentive variable.

The next challenge is to choose the proper dependent variable to study farmers' response to price: area or yield. Supporters of using acreage function believe that output is subject to more fluctuation than area because of uncertain, random factors such as weather. Therefore the price response is likely to be confined mainly to area allocation among crops. Some studies use the share of acreage planted in a crop within the total cropped area to study shifts in area among the crops. This variable has its own limitation, though, because the simultaneous changes in the crop area under study and the total cropped area will conceal variations. Because of this, we use absolute area.

The supply response is actually a two-stage process. In the first stage, farmers allocate land based on expected prices, and in the second stage, they determine yield based on other inputs and climate variables, given the area. Farmers may make substantial revisions in their decisions about other inputs or adopt intensive cultivation by using more or better inputs after they allocate area. The yield reflects the intensive nature of cultivation or quality of inputs. In this case, area response function might underestimate actual level of supply response. Hence it is reasonable to use both area and yield as indicators of supply because farmers make decisions about both area and yield in response to price signals.

Fulginiti and Perrin (1993) argued that the effects of technical change are typically modeled in an ad hoc fashion. Advances in technology that essentially result in higher yield may be confused with supply response and hence may lead to biased estimates of the price coefficients. Some researchers include a linear trend term as an independent regressor, implying the same external source for technology. But such a method lacks validity because technology rarely increases at a constant rate every year. In this paper, we use fertilizer usage (percentage of cultivated area irrigated) as a measure of the contribution of technical progress. Fertilizer consumption is a critical precondition and one of the most important determinants of area growth, along with high-yield varieties, irrigation, and crop intensity. In order to capture the progress of infrastructure, we introduce investment in fixed assets, telephone coverage, and primary school enrollment as indicators for capital accumulation, telecommunication coverage, and education accessibility.

Estimation Methodology

Usually there is a delayed adjustment in agricultural markets due to the availability of resources and the cycle of agricultural production. Thus, it is essential to adopt a dynamic approach in empirical analysis that recognizes the time lags in agricultural supply response. However, previous studies of Chinese supply response are generally static and do not take the issue of endogeneity in production process into consideration.

In light of new developments in the use of time series and econometric techniques, we are able to estimate distinct short- and long-run elasticities. Several recent papers used a time-series approach like the error correction model (ECM) and cointegration to estimate agricultural supply response (Muchapondwa 2008; Olubode-Awosola, Oyewumi, and Jooste 2006). Others used simultaneous equations to estimate the supply responses for a set of crops (Vitale, Djourra, and Sidibe 2009). But time-series analysis for one cross-sectional unit will miss the county-specific characteristics and prevent us from providing better information that can be used to draw inferences at the county level. In contrast, panel data enable us to capture both regional and temporal variations in a dynamic fashion. This paper estimates the supply response to price changes in three agricultural subsectors by applying dynamic panel data techniques. Our methods employ sufficient information about the whole time period and individual heterogeneity to investigate dynamic relationships and obtain consistent parameter estimates (Bond 2002).

Our methods account for both the simultaneity problem and the possibility of nonstationary variables. First, the specified supply relationship implies that there is a unidirectional causality from independent variables such as price to agricultural supply but not vice versa. In reality, it may well be the case that price and supply are determined simultaneously, in which case estimates suffer from demand–supply simultaneity bias. In the case of grain, such as maize and other coarse grain, the price of wheat in Henan province is likely exogenous. That is because the Henan price depends on the national price and production, and the latter do not necessarily depend on Henan's production. Nevertheless, the price of wheat in Henan is probably endogenous because the province's share of national production is substantial. Failure to deal properly with the simultaneity problem gives rise to inconsistent estimates.

Second, any variable series included in the analysis might not be stationary, that is, unit roots exist. In this study, a generalized method of moments (GMM) estimator is used to gauge the supply response function based on a dynamic panel data model, taking both endogeneity and dynamic panel bias into consideration.

Let us assume that there are *N* counties observed over *T* periods. Let us also assume that *i* indexes the county and *t* indexes the time period. The model to be estimated is specified thus:

$$\begin{aligned} y_{it} &= \alpha_0 + \sum_{e=1}^{m} \alpha_e y_{i,t-e} + \sum_{k=1}^{n} \beta_k x_{i,t-k} + \lambda_t + \eta_i + u_{it} \\ E(\eta_i) &= E(u_{it}) = E(\eta_i u_{it}) = 0 \qquad i=1,\ldots,N; \quad t=m+2,\ldots,T; \end{aligned} \tag{5}$$

where *y* is a supply response variable, which can be either crop output or yield; *x* is a set of independent variables (real output prices and exogenous variables), all in logarithmic form; α's and β's are parameters to be estimated; and λ_t is time dummies. Here the disturbance term has two orthogonal components: the stochastic individual effects η_i and the idiosyncratic shocks *u*. Furthermore, the lag lengths *m* and *n* are sufficient to ensure that *u* is a stochastic error. While it is not essential that *m* equal *n*, we follow typical practice by assuming that they are identical.

Expressed in matrix, the (*T-m*) equations for individual *i* in Equation (5) are

$$Y_i = W_i \delta + \phi_i \eta_i + u_i \qquad i=1,\ldots,N, \tag{6}$$

where δ is a parameter vector including the α's and β's; W_i is a data matrix containing the time series of the lagged dependent variable *y*'s and *x*'s and the time dummies; and ϕ_i is a vector of ones to capture individual endogeneity.

After a certain transformation of Equation (6), that is in first difference, assuming we can find a set of suitable instrumental variables Z_i (which may or may not be entirely internal), and assuming H_i is a possibly individual specific covariance matrix of the transformed errors, the linear GMM estimators of δ are computed as

$$\hat{\delta} = [(\sum_i W_i^{*'} Z_i) A_N (\sum_i Z_i' W_i^*)]^{-1} (\sum_i W_i^{*'} Z_i) A_N (\sum_i Z_i' Y_i^*) , \tag{7}$$

where weighting matrix $A_N = (\frac{1}{N}\sum_i Z_i' H_i Z_i)^{-1}$, and W_i^* and Y_i^* denote some general transformation of W_i and dependent variable Y_i. The GMM estimator is consistent and asymptotically efficient.

The lagged dependent variables are endogenous to the individual effects in the error term in Equation (7), causing dynamic panel bias. Arellano and Bond (1991) proposed a method to estimate a dynamic panel difference model using all suitably lagged endogenous (and predetermined) variables as instruments in the GMM technique, called *difference GMM*. In principle, efficient GMM exploits a different number of instruments in each time period. Difference GMM avoids the trade-off between instrument lag depth and sample depth in 2SLS by including separate instruments for each time period.

Following the approach of Arellano and Bond (1991), Equation (6) is thus transformed into a first-difference equation:

$$\Delta y_{it} = \sum_{e=1}^{m} \alpha_e \Delta y_{i,t-e} + \sum_{k=1}^{n} \beta_k \Delta x_{i,t-k} + \Delta \lambda_t + \Delta u_{it} \quad . \tag{8}$$

At time *t*, if u_{it} are not serially correlated with each other, lagged dependent variables ($y_{i1}, y_{i2}, ..., y_{i,t-2}$) are uncorrelated with Δy_{it} and therefore can be used as valid instruments for difference Equation (8) at time *t+2*.

The GMM estimator makes full use of the conditional expectation of the product of the lagged dependent variable and all the moment equations. The estimation retains the error component with panel-specific random terms. First-differencing the variables eliminates the panel-specific effects and leaves out purely random terms. By first-differencing we also adjust for nonstationarity of the series. GMM is a suitable method for estimating reduced-form equations involving lagged dependent variables and is therefore used for this study.

4. DATA AND VARIABLES

We obtained the county-level area, yield, and other related variables for 1998–2007 from *Henan statistical yearbook* (various years). There are 109 counties in the province, but Jiyuan was dropped due to data constraint. Among the remaining 108 counties, 66 are in the flat Plain zone, 26 in the Hill zone and 16 in the Mountain zone. The sample covers the major grain-producing areas in the province. As Table 4 shows, the sample covers 91 percent of cultivated area, 92 percent of grain-sown area, and 96 percent of grain production. The Plain zone is the main region for grain production, accounting for 66 percent of grain-planted area and 70 percent of provincial output.

Table 4. Sample representation

	Share in provincial cultivated area	Share in provincial grain-sown area	Share in provincial grain output	Average yield
	%	%	%	Ton/kg
Plain zone (66 counties)	63.5	64.6	71.2	6.1
Hill zone (26 counties)	19.9	19.4	18.6	5.3
Mountain zone (16 counties)	8.1	7.8	6.6	4.7
Sample (108 counties)	91.5	91.8	96.3	5.8

Source: Authors' calculation from *Henan statistical yearbook* 2008.

We focus on acreage and yield response of three crops in this study: grain, cotton, and oilcrops. Three output prices and one input price are included: wheat, cotton, oilcrops, and labor wages. The price of wheat is used to proxy grain price because wheat accounts for more than half of grain output and area, and there is a high correlation between wheat and other grain prices. These prices are deflated by the price of input—fertilizer—to normalize output prices. The use of "real" rather than actual price as regressor reduces multicollinearity in prices. At the time of production decision, acreage is allocated based on known output prices from last year as expected prices. Economic theory suggests that crop response should be encouraged when the price of a complementary crop increases and should be discouraged when the price of a competing crop increases.

Other factors affect supply response, including biophysical conditions, infrastructure, capital investment, and government policies. Biophysical conditions include temperature and rainfall. The climate data are from approximately 700 climate stations in China, of which about 120 are located within Henan province. We calculated county monthly minimum temperature and rainfall by averaging those stations within the county or, in case of missing climate stations, taking the neighboring county's observations (Feng, Hu, and Qian 2004). We assume farmers make land allocation based on soil moisture level, which is partly determined by rainfall in the last season. Therefore, total rainfall variables are used in the estimation of both area and yield response functions. Yield is affected by both rainfall and minimum temperature; therefore average minimum temperature is applied only to yield functions.

We use three indicators to capture the level of infrastructure construction at the county level. Access to social services is represented by the enrollment rate of primary school. Amount of fertilizer application is used as a proxy to capture farmers' access to input and output markets. We also include number of telephones per capita in our information on physical infrastructure. Due to data limitation, the telephone variable covers only the period of 2001–2006. Investment in fixed assets per hectare captures the intensity of continuous investment in physical assets like machinery, buildings, irrigation facilities, and technology for each county. Because machinery and irrigation are included in the fixed-asset investment, they are not used in the estimation in order to avoid a multicollinearity problem.

We also use two exogenous variables to represent government policies for the agricultural sector and grain subsector. Effective tax rate is used to investigate the impact of agricultural tax policy by dividing provincial government agricultural tax revenues by their corresponding nominal gross agricultural products. China has implemented various subsidies to promote grain production. The provincial-level grain subsidy, set in 2004, is also included in the study to quantify the impact of grain subsidy on the responsiveness of grain and non-grain crops. We expect the signs of all the variables to be positive except for tax rate.

Table 5 summarizes the variables and their definitions. Table 6 depicts the growth pattern for the three groups of crops. Both output and area increased in the past decade for both grain and oilcrops. However, output of cotton declined because of drops in both planting area and yield.

Table 5. Variable definitions

Variable	Definition
Area variables	
lngrainarea	Logarithm of sown grain area
lncottonarea	Logarithm of sown cotton area
lnoilarea	Logarithm of sown oilcrops area
Yield variables	
lngrainyield	Logarithm of grain yield
lncottonyield	Logarithm of cotton yield
lnoilyield	Logarithm of oilcrops yield
Input and output prices	
lnpwheat	Logarithm of real price of wheat
lnpcotton	Logarithm of real price of cotton
lnpoil	Logarithm of real price of oilcrops
lnwage	Logarithm of real wages in agricultural sector
Natural condition variables	
winterrain	Total amount of rainfall in mm during winter season, November–April
summerrain	Total amount of rainfall in mm during summer season, May–October
wintermintemp	Average minimum temperature in Celsius during winter season, November–April
summermintemp	Average minimum temperature in Celsius during summer season, May–October
Infrastructure variables	
lnprimary	Logarithm of primary school enrollment rate
lnpafer	Logarithm of fertilizer consumption per hectare
lnpcphone	Logarithm of per capita telephone access
Investment variables	
lnpaasset	Logarithm of fixed asset stock per hectare
Policy variables	
tax rate	Effective tax rate in percentage
subsidy	Amount of provincial subsidy for grain production and agricultural productive inputs, in Yuan per mu

Source: Authors.

Table 6. Growth of subsector crops in Henan province, 1998–2007

	Output 000 tons	Area 000 ha	Yield Tons/ha
		Grain	
1998	37,900	8,410	4.5
2001	38,633	8,082	4.8
2004	41,291	7,956	5.2
2007	50,524	8,689	5.8
Growth rate (%)	2.8	0.3	2.5
		Cotton	
1998	803	766	1.0
2001	839	772	1.1
2004	627	875	0.7
2007	674	689	1.0
Growth rate (%)	-2.3	-0.4	-1.9
		Oilcrops	
1998	2,951	1,178	2.5
2001	3,425	1,360	2.5
2004	3,842	1,450	2.6
2007	4,517	1,397	3.2
Growth rate (%)	4.1	1.9	2.1

Source: Authors' calculation.

5. EMPIRICAL ANALYSIS OF ACREAGE, YIELD, AND SUPPLY RESPONSE

We first test the variables for panel unit roots using the approaches suggested by Im, Pesaran, and Shin (2003); Pesaran (2007); and Hadri (2000) with one lag and no trend. Based on test results, we fail to reject the null hypothesis of nonstationarity in the level of variables (Table 7). When the tests are conducted on the first differences of these variables we firmly reject the null hypothesis of nonstationarity for most variables, and hence we conclude that they are integrated of order one (I(1)). The unit root test shows that prices, sown area and yield, labor supply, and irrigation intensity are integrated of order one and the difference approach ensures that all variables are stationary. The dynamic panel data model is applied to annual data on area and yield response at the county level for grain, cotton, and oilcrops, and the results are summarized in Tables 8a and 8b.

Table 7. Panel unit test

	Im, Pesaran and Shin (2003)		Pesaran (2007)		Hadri (2000)	
	H0: nonstationarity		H0: nonstationarity		H0: stationarity	
	Level	Difference	Level	Difference	Level	Difference
lngrainarea	0.536	0.000	1.000	0.002	0.000	0.909
lncottonarea	0.000	0.000	0.804	0.358	0.000	0.932
lnoilarea	0.883	0.000	0.032	0.000	0.000	0.917
lngrainyield	0.065	0.000	0.999	0.053	0.000	1.000
lncottonyield	0.000	0.000	0.689	0.000	0.000	1.000
lnoilyield	0.209	0.000	1.000	0.000	0.000	0.999
lnprimary	0.000	0.000	1.000	0.997	0.955	1.000
lnpafer	0.004	0.000	0.000	0.000	0.000	0.275
lnpcphone	0.000	0.000	1.000	1.000	0.000	0.900
lnpaasset	0.997	0.046	1.000	0.038	0.000	0.000
	ADF					
	H0: stationarity					
	Level	Difference				
lnpwheat	0.053	0.045				
lnpcotton	0.048	0.035				
lnpoil	0.055	0.045				
lnwage	0.083	0.037				

Source: Authors' calculation.

We will now develop some hypotheses about the relationship between crop response and the independent variables. Based on economic theory, we expect that farmers respond to higher own-price with higher area allocation and more intensified production process. The coefficients of complementary crop should be positive and the coefficients of competing crop negative. If input price rises, a rational farmer will prefer a less labor-intensive crop so as to be more efficient in labor use. Generally speaking, the impact of rainfall and temperature on crop yield is hard to predict, depending on the crop and deviation from long-term normal. The quality of labor force is reflected by primary school enrollment rate, and a literate farmer should be able to respond quickly to market signal. Fertilizer consumption is chosen as a proxy for market access and the expected sign of this variable is positive. Another infrastructure variable, landline telephone access, should boost yield through improved access to information. Since infrastructure is a result of continuous investment in transportation, telecommunication, and technology, the coefficient of capital stock should be positive. The decline in agricultural tax rate provides an incentive for farmers to increase output, and we expect a positive sign for this variable. Additional grain subsidies are likely to encourage grain production while discouraging other crop production.

Table 8a. Area and yield response in Henan province, 1998–2007

	Area Response			Yield Response		
	lngrainarea	lncottonarea	lnoilarea	lngrainyield	lncottonyield	lnoilyield
dependent variable (-1)	0.661	0.019	0.374	-0.004	0.090	0.042
	(7.65)***	(0.22)	(4.54)***	(-0.09)	(1.74)*	(0.89)
Input and output prices						
lnpwheat (-1)	0.274	0.669	0.036	0.261		
	(4.57)***	(1.52)	(0.25)	(4.12)***		
lnpcotton (-1)	-0.036	0.738	-0.052		1.136	
	(-1.15)	(2.77)***	(-0.75)		(5.09)***	
lnpoil (-1)	-0.197	-1.002	-0.024			0.783
	(-2.90)***	(-1.65)*	(-0.14)			(4.46)***
lnwage (-1)	-0.081	-0.322	0.317	0.228	1.628	0.869
	(-2.89)***	(-1.27)	(3.73)***	(3.41)***	(5.72)***	(5.61)***
Natural condition variables						
summerrain	0.000	-0.008	-0.001	0.000	0.014	-0.003
	(0.75)	(-1.78)*	(-0.73)	(0.29)	(4.28)***	(-2.53)**
winterrain	-0.000	-0.005	-0.006	-0.001	0.020	-0.008
	(-0.11)	(-0.60)	(-2.39)**	(-0.47)	(2.15)**	(-1.29)
summermintemp				-0.008	-0.032	-0.009
				(-1.74)*	(-2.46)**	(-0.87)
wintermintemp				0.016	0.365	0.052
				(2.36)**	(6.14)***	(4.03)***
Infrastructure variables						
lnprimary	0.255	-0.231	0.305	-0.024	3.480	1.265
	(0.84)	(-0.14)	(0.39)	(-0.04)	(1.77)*	(1.00)
lnpafer	-0.008	0.021	0.061	-0.018	0.091	0.011
	(-0.74)	(0.40)	(2.39)**	(-0.56)	(0.98)	(0.19)
Investment variables						
lnpaasset (-1)	0.088	0.304	-0.013	-0.100	-0.322	-0.153
	(5.32)***	(2.71)***	(-0.37)	(-2.35)**	(-2.93)***	(-1.59)
Policy variables						
tax rate	-0.003	-0.026	-0.017	-0.038	-0.219	-0.077
	(-0.41)	(-0.31)	(-0.87)	(-3.23)***	(-5.84)***	(-3.25)***
subsidy	-0.013	-0.090	-0.017	0.027	-0.132	0.020
	(-2.93)***	(-2.33)**	(-1.84)*	(4.38)***	(-4.55)***	(1.40)
Constant	0.418	2.067	-1.992	1.118	-17.051	-0.440
	(0.27)	(0.28)	(-0.56)	(0.36)	(-1.78)*	(-0.07)
AR(1)	0.000	0.000	0.000	0.000	0.000	0.000
AR(2)	0.333	0.138	0.258	0.563	0.983	0.921
P-value of Sargan exogeneity test	0.009	0.000	0.000	0.000	0.000	0.000
Observations	972	954	972	972	954	972
Number of counties	108	106	108	108	106	108

Source: Authors' calculation.
Note: Z-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table 8b. Area and yield response in Henan province with telephone access, 2001–2006

	Area Response			Yield Response		
	lngrainarea	lncottonarea	lnoilarea	lngrainyield	lncottonyield	lnoilyield
dependent variable (-1)	0.537	0.035	0.452	-0.129	-0.074	-0.004
	(3.42)***	(0.34)	(4.62)***	(-1.54)	(-0.70)	(-0.05)
Input and output prices						
lnpwheat (-1)	0.339	-0.496	-0.023	-0.025	0.315	-0.602
	(2.02)**	(-0.70)	(-0.09)	(-0.22)	(1.46)	(-1.52)
lnpcotton (-1)	0.063	2.034	-0.165			
	(0.74)	(5.33)***	(-1.53)			
lnpoil (-1)	-0.179	0.058	0.127			
	(-1.47)	(0.12)	(0.70)			
lnwage (-1)	-0.629	-3.777	0.234	0.281	-2.183	0.799
	(-2.64)***	(-4.16)***	(0.77)	(0.75)	(-2.06)**	(0.97)
Natural condition variables						
summerrain	-0.001	-0.020	0.002	-0.001	0.005	0.005
	(-1.30)	(-4.29)***	(1.33)	(-0.33)	(0.87)	(1.23)
winterrain	0.010	0.017	-0.002	-0.022	0.033	-0.052
	(2.06)**	(0.86)	(-0.38)	(-2.90)***	(1.13)	(-3.09)***
summermintemp				0.010	-0.056	0.081
				(0.39)	(-0.75)	(1.33)
wintermintemp				0.011	0.287	0.113
				(0.66)	(3.51)***	(2.95)***
Infrastructure variables						
lnprimary	-0.209	-1.078	1.132	1.380	6.584	4.718
	(-0.41)	(-0.55)	(1.25)	(1.07)	(1.83)*	(1.81)*
lnpafer	-0.019	-0.005	0.028	-0.117	-0.456	0.222
	(-1.14)	(-0.08)	(0.96)	(-1.08)	(-1.88)*	(1.52)
L.lnpcphone	0.248	0.130	-0.283	0.567	1.556	1.101
	(2.93)***	(0.49)	(-1.95)*	(2.87)***	(2.38)**	(2.32)**
Investment variables						
lnpaasset (-1)	0.025	0.308	-0.017	-0.054	-0.540	-0.279
	(1.09)	(3.65)***	(-0.56)	(-1.18)	(-3.52)***	(-2.53)**
Constant	7.792	30.156	-5.776	-5.438	2.271	-13.392
	(2.50)**	(2.43)**	(-1.12)	(-0.80)	(0.11)	(-0.92)
AR(1)	0.000	0.000	0.000	0.000	0.000	0.000
AR(2)	0.268	0.674	0.814	0.364	0.044	0.979
P-value of Sargan exogeneity test	0.998	0.249	0.002	0.000	0.000	0.021
Observations	648	636	648	648	636	648
Number of counties	108	106	108	108	106	108

Source: Authors' calculation.
Note: Z-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Acreage Response

The GMM approach is applied to a balanced panel of 108 counties over the period of 1998–2007. Production data in 1999–2007 and price data in 1998–2006 are used due to the lag structure of the dynamic model. Let us first consider the area response equations, shown in the first three columns of Table 8a. Most variables are significant and of the expected sign. The estimated grain acreage response model (in the first column) provides a good fit. The coefficients of the estimated parameters for the response of grain to its own-price and to the price of oilcrops are significant and consistent with standard production theory: a positive supply response to own-price and a negative response to competing crop price. The results reveal that grain acreage is significantly influenced by the prices of wheat and oilcrops. When the price of wheat rises by 1 percent, farmers choose to increase the share of their land allocated to grain cultivation by 0.27 percent. When the price of oilcrops rises by 1 percent, farmers are likely to decrease the land share they allocate to grain by 0.20 percent. The responses of cotton area (in the second column) with respect to cotton and oilcrops prices are large, suggesting the land allocated for cotton cultivation is more volatile than that of other crops, probably because cotton production is completely market-oriented. Coefficients of prices for oilcrops acreage (third column) are not significant, indicating that oilcrops are competing crops for grain but not vice versa, which is consistent with the crop calendar (Meng et al. 2006). The acreage response of grain to real labor cost is negative and significant, while the oilcrops acreage responds positively to higher labor cost. The results suggest that farmers choose to put more labor into high-return oilcrops and less into grain as real wages increase.

We consider total rainfall from the previous growing season for both summer and winter crops. Increased rainfall decreases the land cultivated under cotton and oilcrops. This is partly because cotton and oilcrops are mostly grown in dry environments and excess soil moisture could hinder crop production. Farmers therefore reduce the area devoted to cotton and oilcrops as a short-term strategy to adapt to excess rainfall.

The indicator of education accessibility, enrollment rate in primary school, has a large but insignificant coefficient, which is not surprising in the case of Henan. The province has achieved universal primary education in more than half of its counties, so there is little heterogeneity in this variable. Increasing fertilizer application by 1 percent could boost the cultivation area of oilcrops by 0.06 percent if everything else remains constant. Coefficients for investment in fixed assets are significant for grain and cotton. Their positive signs agree with our expectation that an improved external environment will facilitate farmers' access to markets and adoption of modern technology, thereby improving supply responsiveness through synergetic effects among factors influencing production process (seed, fertilizer, and market information, among others). The results underscore the importance of infrastructure and technology in improving crop yield.

Coefficients for the effective agricultural tax are negative but insignificant. The variable subsidy captures the government's support for grain production, and the coefficients are negative for all crops. The negative responses of non-grain crops (cotton and oilcrops) at the increase of grain subsidy are as expected, since grain subsidy discourages the allocation of resources to non-grain crops. However, the negative coefficient of subsidy for grain area function suggests that subsidy does not increase area devoted to grain production. In policy implementation, the exact amount of subsidies received by farmers is based on the household's total crop cultivation area instead of actual grain cultivation area. As a result, grain subsidy becomes another form of income subsidy because the additional income is not directly linked to farmers' grain area allocation. Although the grain subsidy is intended to encourage grain production, there is little evidence to suggest the policy achieves its purpose of encouraging farmers to assign higher priority to grain crops.

Yield Response

Turning to the yield equations (the next three columns of Table 8a), we find that own-price response is significant and positive for grain. When grain price increases by 1 percent, average grain yield increases by 0.26 percent. The coefficients of own-price elasticities of the yield response functions of cotton and oilcrops are positive and large, 1.14 for cotton and 0.78 for oilcrops, suggesting that yield of cash crops is more responsive to price signals than is the yield of grain, which is consistent with our expectation. Yield responds to labor wages positively, with the highest elasticity for cotton yield, at 1.63. The magnitude of coefficients matches our expectations since grain is more mechanized and less labor-intensive than the other crops. In contrast, cotton is handpicked, placing a high demand on labor. The positive signs of the wage coefficients suggest that farmers are more efficient and more productive when the cost of hiring labor rises.

Rainfall relates negatively to oilcrops yield but positively to cotton yield. We also considered average winter and summer minimum temperature in the yield response to capture year-to-year variations of exogenous climatic conditions. The coefficients for average summer minimum temperature are negative in grain and cotton yield response functions. This is because a higher temperature during the summer is harmful for crop growth. It also implies that global warming due to climate change would have a negative impact on crop yield, consistent with many studies (You et al. 2009; Peng et al. 2004) On the other hand, coefficients of winter minimum temperature are positive and significant for all crops, suggesting that a rise in ground temperature could lift the yield of winter crops. Too-low temperature during the winter would slow down the crop growth or even damage the crops.

Other nonprice, nonclimatic factors also contribute to yield response, and these include labor quality and infrastructure. The coefficient for primary school enrollment is large and positive for cotton yield function. Many researchers have argued that chemical fertilizer has been overused in China, causing adverse environmental consequences without further improvement in productivity. Our results confirm this observation: Fertilizer consumption intensity, a proxy for market access and technology, does not demonstrate any positive influence on the yield. Although capital stock of fixed assets is negatively associated with crop yield, we find it is positively correlated with crop area, with more or less similar magnitude. This is probably attributable to an urban-biased investment strategy, which does not bring growth in agricultural productivity despite fast growth in infrastructure such as transportation and communication.

The declining agricultural tax generates coefficients with expected signs across all three groups. When the agricultural tax rate drops by one percentage point, the average yield of grain and oilcrops increases by 0.04 and 0.08 percent, respectively. Cotton farmers relieved from the heavier tax burden are more productive, with a 0.22 percent increase in yield for each percentage point drop in tax rate. The implementation of grain and comprehensive subsidies stimulate grain production but suppress cotton production. If total subsidies for grain production increase by one Yuan per mu, average grain yield could increase by 0.03 percent while cotton yield may drop by 0.13 percent.

Statistical Test and Regional Difference

Table 8b reports the area and yield responses correlated with telephone accessibility. The government policy variables are dropped due to multicollinearity in the sample years of 2001–2006. The results are similar to Table 8a but of different magnitude. Coefficients for telephone access are positive and significant for all yield response functions. It is worth noting that average yield of cotton and oilcrops could surge by 1.56 and 1.10 percent respectively when telephone availability increases by one percentage point. When combined with grain area response, elasticity of grain output with respect to telephone access is 0.81.

The GMM estimator is consistent only if there is no second-order serial correlation in the idiosyncratic error term of the first-difference equations. Arellano and Bond (1991) developed a z-test for serial correlation that would render some lags invalid as instruments. If the disturbances are not serially correlated, there should be evidence of significant negative first-order autocorrelation in differenced residuals and no evidence of second-order autocorrelation in the differenced residuals. As expected, the output above presents strong evidence against the null hypothesis of zero autocorrelation in the first-differenced errors at order 1, AR(1). If serial correlation in the first-differenced errors is found at an order higher than 1, the moment conditions for estimation are not valid. The AR(2) test result presents no significant evidence of serial correlation in the first-differenced errors at order 2 and thus indicates that our GMM estimator is consistent.

The Nerlovian model can be criticized on the basis of misspecification since it omits other important determinants of output such as infrastructure and government policy. In this study we estimate an extension of the Nerlovian model, whereby external factors are incorporated. Indeed, the Sargan test for the exclusion of these variables yields a significant chi-square in all equations in Tables 8a and 8b. Hence we conclude that the above Nerlovian model is not misspecified.

The results from the dynamic panel data model show a significant area and yield supply response to price changes. Table 9 reports estimates of the short- and long-run elasticities of grain, cotton, and oilcrops with respect to their prices and to exogenous variables in Henan, based on Table 8a. The elasticities for lagged own-prices are all positive and small, except for oilcrops area response, confirming that price and output have moved in the same direction in both the short and long run but the output change is smaller than the price change. The response of grain area to its own-price is positive and significant, with own-price supply response elasticity at 0.27 in the short run and 0.81 in the long run. The yield elasticities with respect to grain price are also less than one in both the short and long run, demonstrating the rigidity of the grain sector. The impact of labor wages is negative in area response but positive in yield response, indicating that farmers respond rationally to input cost increase by decreasing labor demand at planting time and increasing labor efficiency during production season. The infrastructure variables (education and fertilizer consumption) are not significant in most cases, and the large coefficients reflect farmers' urgent need for human capital in cotton cultivation. Capital investment affects agricultural supply mainly through its positive impact on area allocation instead of yield improvement, suggesting such investment is directly related to the agricultural sector. The coefficients for government policies are almost all significant and of the expected sign. Declining agricultural tax enhances crop output through improved productivity instead of land expansion. Various subsidies targeting grain output for food security boost grain yield while reducing area allocated for cotton and oilcrops and dampening cotton yield. These results suggest there are more effective ways to boost agricultural output through investment in technology and improved government policy. Our results are consistent with those of previous literature on supply response.

Table 9. Short- and long-run elasticities in Henan province, 1998–2007

	Area Response			Yield Response		
	Grain	Cotton	Oilcrops	Grain	Cotton	Oilcrops
Short-run elasticity						
wheat price	0.274	0.669	0.036	0.261		
cotton price	-0.036	0.738	-0.052		1.136	
oilcrops price	-0.197	-1.002	-0.024			0.783
wages	-0.081	-0.322	0.317	0.228	1.628	0.869
enrollment rate of primary school	0.255	-0.231	0.305	-0.024	3.48	1.265
fertilizer use	-0.008	0.021	0.061	-0.018	0.091	0.011
capital stock	0.088	0.304	-0.013	-0.100	-0.322	-0.153
tax rate	-0.003	-0.026	-0.017	-0.038	-0.219	-0.077
subsidy	-0.013	-0.090	-0.017	0.027	-0.132	0.020
Long-run elasticity						
wheat price	0.808	0.682	0.058	0.260	0.000	0.000
cotton price	-0.106	0.752	-0.083	0.000	1.248	0.000
oilcrops price	-0.581	-1.021	-0.038	0.000	0.000	0.817
wages	-0.239	-0.328	0.506	0.227	1.789	0.907
enrollment rate of primary school	0.752	-0.235	0.487	-0.024	3.824	1.320
fertilizer use	-0.024	0.021	0.097	-0.018	0.100	0.011
capital stock	0.260	0.310	-0.021	-0.100	-0.354	-0.160
tax rate	-0.009	-0.027	-0.027	-0.038	-0.241	-0.080
subsidy	-0.038	-0.092	-0.027	0.027	-0.145	0.021

Source: Authors' calculation.

Note: Tax rate and subsidy are reported as percent outcome increase given 1 unit increase in policy variables.

The influence of the explanatory variables varies considerably among the three geographical zones. For grain crops, own-price affects area response across all three zones but has more impact on yield response in the Plain zone than elsewhere (Table 10a). Cotton and oilcrops are competing for land resources with grain. Increased labor cost dampens area response for grain in the Hill zone but improves productivity in the Plain zone. Investment in infrastructure helps integrate farmers into the market and thus elevates responsiveness to market signals. The supply response of the grain sector can be further elicited through favorable government policies such as lower tax rate and direct subsidy.

Table 10a. Short- and long-run grain elasticities by zone, 1998–2007

	Area Response			Yield Response		
	Plain	Hill	Mountain	Plain	Hill	Mountain
Short-run elasticities						
wheat price	0.319	0.223	0.387	0.415	0.152	0.176
cotton price	0.028	-0.044	-0.096			
oilcrops price	-0.306	-0.155	-0.334			
wages	-0.047	-0.172	-0.048	0.379	-0.287	0.207
enrollment rate of primary school	0.282	0.096	-0.888	0.338	-2.020	-0.011
fertilizer use	-0.011	0.037	0.081	-0.015	-0.005	0.134
capital stock	0.058	0.083	0.052	-0.228	-0.150	-0.033
tax rate	-0.028	0.009	-0.012	-0.075	-0.039	-0.014
subsidy	-0.017	-0.006	-0.013	0.032	0.075	0.022
Long-run elasticities						
wheat price	0.952	0.551	0.975	0.437	0.142	0.198
cotton price	0.084	-0.109	-0.242			
oilcrops price	-0.913	-0.383	-0.841			
wages	-0.140	-0.425	-0.121	0.399	-0.269	0.233
enrollment rate of primary school	0.842	0.237	-2.237	0.356	-1.893	-0.012
fertilizer use	-0.033	0.091	0.204	-0.016	-0.005	0.151
capital stock	0.173	0.205	0.131	-0.240	-0.141	-0.037
tax rate	-0.084	0.022	-0.030	-0.079	-0.037	-0.016
subsidy	-0.051	-0.015	-0.033	0.034	0.070	0.025

Source: Authors' calculation.
Note: Tax rate and subsidy are reported as percent outcome increase given 1 unit increase in policy variables.

Table 10b reports that cotton area responds to price and investment only in the Hill zone. Area of cotton drops when grain price increases or oilcrops price decreases, suggesting grain crops, mostly maize, are competing crops for cotton, while oilcrops and cotton are complementary commodities. Cotton yield response with respect to own-price is elastic in the Plain zone, with an elasticity of 1.05, but inelastic in the Hill zone at -0.46. The impact of higher wages is also different by agroecological zones. Infrastructural factors prompting farmers to boost yield include improvement in human capital (primary school enrollment) and technology (fertilizer application). Higher capital investment brings mixed results across zones, with area increasing in the Plain zone and yield increasing in the Hill zone when investment grows. Cotton yield improves substantially with appropriate policy of low tax rate. As we expected, farmers have fewer incentives to work on labor-intensive cotton cultivation when cotton production is less profitable after the implementation of grain subsidy.

Table 10b. Short- and long-run cotton elasticities by zone, 1998–2007

	Area Response			Yield Response		
	Plain	Hill	Mountain	Plain	Hill	Mountain
Short-run elasticities						
wheat price	0.253	-1.707	-0.988			
cotton price	0.309	-0.566	0.085	1.046	-0.457	-0.002
oilcrops price	-0.134	2.288	0.219			
wages	-0.103	-0.412	0.529	2.072	-0.822	0.513
enrollment rate of primary school	1.822	0.844	-1.038	4.065	-2.974	0.543
fertilizer use	-0.001	0.036	0.495	0.038	0.925	0.167
capital stock	0.314	-0.242	-0.494	-0.412	0.325	-0.337
tax rate	0.102	0.221	-0.066	-0.250	0.091	-0.095
subsidy	-0.051	0.158	0.067	-0.138	0.005	0.032
Long-run elasticities						
wheat price	0.228	-4.332	-1.217			
cotton price	0.278	-1.437	0.105	1.072	-0.497	-0.002
oilcrops price	-0.121	5.807	0.270			
wages	-0.093	-1.046	0.651	2.123	-0.893	0.431
enrollment rate of primary school	1.640	2.142	-1.278	4.165	-3.233	0.457
fertilizer use	-0.001	0.091	0.610	0.039	1.005	0.140
capital stock	0.283	-0.614	-0.608	-0.422	0.353	-0.283
tax rate	0.092	0.561	-0.081	-0.256	0.099	-0.080
subsidy	-0.046	0.401	0.083	-0.141	0.005	0.027

Source: Authors' calculation.
Note: Tax rate and subsidy are reported as percent outcome increase given 1 unit increase in policy variables.

Supply response of oilcrops is mostly from yield response, especially in the Plain zone (Table 10c). Other variables associated with oilcrops supply response include wages, primary school enrollment rate, fertilizer use, capital stock, favorable tax policy, and subsidy. Higher wages promote higher oilcrops output, indicating that farmers choose to allocate more labor to oilcrops for better economic returns when labor cost rises. The negative impact of capital investment resonates with our findings on grain and cotton response and underscores the importance of rural investment for infrastructure and technology.

Table 10c. Short- and long-run oilcrops elasticities by zone, 1998–2007

	Area Response			Yield Response		
	Plain	Hill	Mountain	Plain	Hill	Mountain
Short-run elasticities						
wheat price	-0.102	0.355	0.407			
cotton price	-0.087	0.047	-0.367			
oilcrops price	0.020	-0.427	0.177	1.176	0.529	0.647
wages	0.246	0.671	0.392	1.231	0.078	0.911
enrollment rate of primary school	0.202	2.862	1.652	3.410	-4.334	1.535
fertilizer use	0.025	0.151	-0.003	-0.002	0.422	-0.222
capital stock	-0.137	-0.156	0.054	-0.420	-0.179	-0.350
tax rate	-0.034	-0.102	0.011	-0.147	-0.064	-0.099
subsidy	-0.004	-0.023	-0.002	0.036	0.061	0.066
Long-run elasticities						
wheat price	-0.146	0.574	0.765			
cotton price	-0.124	0.076	-0.690			
oilcrops price	0.029	-0.691	0.333	1.189	0.556	0.698
wages	0.352	1.086	0.737	1.245	0.082	0.983
enrollment rate of primary school	0.289	4.631	3.105	3.448	-4.553	1.656
fertilizer use	0.036	0.244	-0.006	-0.002	0.443	-0.239
capital stock	-0.196	-0.252	0.102	-0.425	-0.188	-0.378
tax rate	-0.049	-0.165	0.021	-0.149	-0.067	-0.107
subsidy	-0.006	-0.037	-0.004	0.036	0.064	0.071

Source: Authors' calculation
Note: Tax rate and subsidy are reported as percent outcome increase given 1 unit increase in policy variables.

6. CONCLUSION

The Chinese economy has undergone drastic transformation, characterized by rapid urbanization and increased incomes. The extensive changes in economic and social structure require fast growth in the food supply. Increasing the productivity of agriculture has been an important objective of the Chinese government. Policy incentives, including tax decreases and subsidies, have been major policy instruments to promote agricultural production. This paper reports the results of acreage and yield supply response models fitted to a sample of 108 counties in one of the major agricultural provinces in China over the 1998–2007 period. The study estimates the agricultural supply response, taking into account the regime's policy change in China's fast transformation. The dynamic panel data approach is appropriate to estimate the short- and long-run relationship between agricultural supply and price while addressing the endogeneity problems raised in earlier literature.

The major findings of this paper are, first, that crops area allocation is responsive to price incentives in both short and long terms. The short-run elasticity for the county-level grain area planted, with respect to own-price, is 0.27, and the corresponding long-run elasticity is 0.81. Future expansion of grain output hinges on policies to improve relative price of grain or to reduce direct cost of grain production, such as setting a minimum procurement price and providing input subsidies. Grain responsiveness to output prices is greater than that to variable input price. This suggests that agricultural policy should focus on output prices and input supply, such as access to credit and market, rather than on input price per se. The recent grain policies by the Chinese government have had a positive effect on grain output, and these policies include ensuring elimination of taxes and fees in the agricultural sector.

Second, there is still great potential to increase crop yield by improving infrastructure and social services, including education, transportation, and communication. Our findings indicate that nonprice factors are important means of affecting crop production and resource allocation, demonstrated by the magnitudes of the elasticities of acreage and yield responses with respect to these factors. The most important nonprice factors determining crop area are capital investment and fertilizer application. The most important nonprice factor determining crop yield, and hence the major source of productivity advance, is primary school enrollment. Given the high impact of school enrollment, investment in improving labor quality still pays high dividends through increased productivity.

Third, government interventions need to emphasize more infrastructure construction in rural areas, as suggested by the large and negative coefficients of investment variables for yield response. Although acreage response to fixed-asset investment is positive, this effect is overshadowed by the larger coefficients of yield response for grain and cotton. Further investment in machinery and transportation in urban areas is unlikely to have an appreciable effect on crop yield, since productivity of the agricultural sector benefits little if farmers are disconnected from technology and information.

Fourth, crop production response is substantially different under different government policies. Subsidies for producing grain and purchasing input encourage farmers to improve grain yield. At the same time, yields of non-grain crops suffer from the deteriorated terms of trade. Producers are motivated to increase crop productivity when effective agricultural tax declines, due to decreased production cost. In this context, the current agricultural policy of tax elimination and input subsidy is effective in increasing crop productivity through proper incentives. However, it is worth noting that the subsidies do not achieve the expected outcome of increasing grain cultivation area because in reality the subsidies are applied universally to all crops instead of specifically targeting grain crops. Given the effectiveness of the subsidy on grain yield response but ineffectiveness on area response, it is sensible to carefully evaluate the overall effect of subsidy policies and design a comprehensive policy package to ensure long-term food security in China.

Our results show that climate affects both crop production and farmers' decisionmaking. Rising temperature, due to climate change over the last few decades, has had a negative impact on crop yields. In addition, as a short-term adaptation strategy, farmers use the previous season's rainfall information and seasonal climate forecasting to adjust the current season's planting areas for different crops (grain, cotton, oilcrops, and others). Future climate change would further raise the temperature and increase the variability of factors such as rainfall in Henan and beyond. These results have valuable policy implications in the formulation of climate change mitigation and adaptation strategies in China. Government policy cannot affect natural conditions like rainfall and temperature, but it can compensate for the negative impact of climate change by increasing investment in irrigation, promoting efficient use of water, and encouraging adoption of drought-resistant varieties. Improving farmers' access to seasonal weather forecast information can be another tool of effective adaptation to climate change.

In summary, the Henan results indicate that Chinese agricultural policy should pay more attention to technological advances and infrastructure improvements. Our findings suggest that China should encourage modernization through investment in infrastructure, labor quality, and agricultural research and development. Policy and public investments would help producers respond more flexibly to price shocks and increase total supply. On the other hand, the effect of climate change on food security cannot be ignored. Many measures can help farmers adapt to climate change. One is improved infrastructure and labor quality as captured by the yield response model. Another measure is investment in agricultural research and development to supply farmers with more drought- and flood-tolerant varieties as well as more efficient production practices that are resilient in adverse soil and weather conditions. A comprehensive package, including both agronomic and economic policies, is needed in the long run to achieve the dual objectives of food security and income growth.

However, the promotion of modern technology and crop diversification should be tailored to local conditions. The impact of public investment can be enhanced significantly if spatial variations are taken into consideration at policy planning and implementation stages. In some regions with challenging geographic conditions, such as the Mountain zone, poor infrastructure and poor information access prevent local producers from benefiting from market conditions. Studies in many developing countries indicate that investments in rural roads yield high returns in poverty reduction by improving rural access to key services (Fan 2008). More investment in rural infrastructure could enable these farmers to collect the latest market information and transport their produce to regional markets.

One limitation of this study is that it does not consider the improvement of grain crop varieties over time, since improved variety is a major driver of crop productivity. It is estimated that new varieties contributed to 20 percent of food crop production increase (Zhu 1997) and that 10 percent of wheat output growth came from variety updating (Lou 2002). In recent years, dominant wheat varieties in Henan province have evolved from high and steady yield to super-high yield, high quality, multi-resistance, and extensive adaptability, ensuring a sustainable and stable growth of wheat yield (Song, Song, and Yin 2007). Meng et al. (2006) also reported that hybrid maize varieties dominated the whole Henan province and no local varieties were cultivated because of the high yield from hybrid varieties. Although information on grain variety remains scarce, it is probably safe to say that new varieties contribute substantially to land productivity based on the historical trend.

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IFPRI HEADQUARTERS

2033 K Street, NW
Washington, DC 20006-1002 USA
Tel.: +1-202-862-5600
Fax: +1-202-467-4439
Email: ifpri@cgiar.org

IFPRI ADDIS ABABA

P. O. Box 5689
Addis Ababa, Ethiopia
Tel.: +251 11 6463215
Fax: +251 11 6462927
Email: ifpri-addisababa@cgiar.org

IFPRI NEW DELHI

CG Block, NASC Complex, PUSA
New Delhi 110-012 India
Tel.: 91 11 2584-6565
Fax: 91 11 2584-8008 / 2584-6572
Email: ifpri-newdelhi@cgiar.org